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Consequences of energy retrofitting for daylight availability in Norwegian apartments based on measurements and simulations

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Abstract

Substituting existing windows for highly insulated glazing systems in Norwegian residential buildings may have a strong impact during the winter season due to the reduction of daylight availability. This paper investigates the consequences on the energy demand for space heating and electricity use for lighting of substituting existing windows with new windows and adding insulation in three apartment buildings located in Trondheim, Norway. The buildings were respectively built before the 1900s, in the first decade of the 1900s, and in the 1960s. The initial U-value of the external facades ranges from 0.96 to 0.26 W/m^{2}K, and is lowered to 0.15 W/m^{2}K after the renovation process. The U-value of the existing windows ranges from 1.6 to 2.8 W/m^{2}K. The new windows have a U-value of 1.1 and 0.6 W/m^{2}K. Scenarios are modelled to simulate the use patterns of artificial lighting in the apartments, based on occupancy schedules and required illuminance thresholds.

Keywords: Daylight Autonomy; energy efficiency: windows; electricity use, lighting

1. Introduction

Daylight and solar radiation have a well-known influence on human health, by regulating the circadian rhythm, mood and behavior, as well as synthesizing vitamin D. Disruptions of day/night cycles are associated with higher

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incidence of cardiovascular diseases, psychological problems, depression, and reduction in cognitive functions [1-6]. In such a perspective, windows are the building's most complex physical interface, as they are required to both allow satisfactory daylight penetration and view to the outdoors, but also limit the thermal exchange between the indoor space and the outdoor environment. This aspect is particularly critical at high latitudes, such as in Trondheim, were the winter conditions require well insulated buildings and high daylight penetration. The relationship between the thermal insulation, the visible transmittance, and the solar energy transmittance of glazing, with either clear or low emissivity glass panes, can be described with an asymptotic curve [7-10]. In practice, improving the thermal insulation of a glazing system will automatically lower its visible transmittance, which in turn has a negative influence on daylight availability in northern climates and increases the use of electricity for indoor lighting [11-13].

1.1. Objective

The scope of this paper is to investigate the consequences on the energy demand for space heating and electricity use for indoor lighting when substituting existing windows (center-glass U-value 1.6 and 2.8 W/m^{2}K) for new better performing windows (center-glass U-value 1.1 and 0.6 W/m^{2}K) commonly used in the upgrading of Norwegian residential buildings.

2. Method

This work is based on the case studies of three apartments, which are described in Table 1. The types of buildings used for the analysis, represent the majority of existing residential constructions in Norway. In order to obtain an accurate daylight analysis in the three apartments, the reflectance of the internal surfaces and the furniture is measured using a Minolta LS-100 luminance meter. This is done by comparing the luminance values measured on the internal surfaces with those measured on a standard grey card with an 18% reflectance. The resulting reflectance is used to characterize the corresponding surface in the 3-D model built for the daylighting analysis, which is performed in Daysim [16]. The illuminance values are calculated on a grid of 0.43 m cell size, located at 0.80 m above the floor level of the apartments. The illuminance results are validated through on-site illuminance measurements, which are not reported in this paper due to space limitations. The occupancy schedules and the type of tasks performed by the building users are modelled according to three suggested minimum illuminance levels, as shown in Table 2. The occupancy time during which the daylight simulations are performed is between 7:30 am and 11:30 pm, of which a 60% occupancy schedule is used to represent an average behavior of residential users. The three lighting levels modelled (100 lux, 300 lux, and 500 lux) are chosen to reflect three possible user activities requiring specific minimum illuminance levels [14]. The combination of the above parameters yields the scenarios presented in Table 2, and for which the Daylight Autonomy (DA) is calculated. The DA is the percentage of occupied hours in a year during which a given minimum illuminance level is met by sole daylighting and is described as:

$$DA = \frac{\sum_i (wf_i \cdot t_i)}{\sum_i t_i} \in [0,1] \quad \text{with} \quad wf_i = \begin{cases} 1 \; if \; E_{daylight} \geq E_{limit} \\ 0 \; if \; E_{daylight} < E_{limit} \end{cases} \tag{1}$$

Where t_i is the occupied time; wf_i is a weighting factor depending on $E_{daylight}$ and E_{limit}, which are the horizontal illuminance on the measuring plane given by daylight only, and the limit value of illuminance [15]. The DA calculation is performed with Daysim. Electricity use for lighting is calculated for three types of luminaires: compact fluorescent, LED, and a combination of the two above. The additional electricity use for lighting is calculated in kWh/year for all the scenarios and the three types of luminaires as:

$$Var.el.light. = el.light._{new\ windows} - el.light._{existing\ windows} \tag{2}$$